DREDGING WATER QUALITY EVALUATION

INTRODUCTION

This memorandum provides a description of the tools that will be used to evaluate the potential water quality impacts of dredging operations and thereby determining the possible need for application of physical turbidity controls during dredging, as part of the Portland Harbor Remedial Investigation/Feasibility Study (RI/FS). These evaluations are intended to provide information that will be used to develop the FS alternatives, specifically with respect to any potential need to assume physical controls (e.g., silt curtains) that should be included as part of dredging technologies. For FS alternative development purposes, it will be assumed that a certain level of operational controls will be included in each dredging project, and this will be reflected in the range of production rates considered for dredging technologies. The evaluations described in this memorandum are intended to consider whether additional *physical* controls costs should be included in the FS alternatives involving dredging.

This memorandum is not intended to provide final decisions as to whether physical controls would or would not be necessary during remedial design and/or used during construction. That level of detailed evaluation will need to be made on a case-by-case basis for each Sediment Management Area (SMA) during remedial design. Rather, this evaluation is solely intended to inform FS-level assumptions for the FS alternatives. The results of these evaluations will be considered further in the detailed evaluation of alternatives in the FS to make a final determination of where (i.e., in what SMAs) physical controls may be included in dredging alternatives.

Other aspects of dredging evaluations included in the Lower Willamette Group's (LWG's) July 1, 2010 check-in topics list have already been presented to the U.S. Environmental Protection Agency (EPA) during the December 14, 2010 check-in including:

- Dredge depth and volume determination methods
- Slope stability assumptions in volume determinations
- Site use factors in volume determinations (e.g., docks, navigation requirements, and site constraints)

Also, costing approaches for dredging options were presented in the LWG memorandum on costing tools dated March 16, 2011.

The following sections describe the types of water quality controls that are typically considered for dredging projects, and provide details on the evaluations that will be performed during FS alternative development to help determine whether physical controls will be included for specific SMAs.

TYPICAL WATER QUALITY CONTROL STRATEGIES

Water quality management strategies employed during dredging can be categorized as either operational controls or physical (i.e., engineered) controls. Experience suggests operational controls, (e.g. best management practices such as controlling dredge cycle time, preventing dredge bucket overfilling, etc.) do not have the same limitations as physical controls (USACE 2008a, Bridges et. al. 2010). As previously stated, for FS alternative development it will be assumed that a certain level of operational controls will be included for dredging technologies.

Physical controls include the use of engineered barrier systems to enclose the dredging operation and isolate the dredging work from the surrounding water. Examples of physical controls include silt curtains, bubble curtains, and sheet piles. There can be significant difficulties associated with the use of physical controls (Francingues and Palermo 2006; USACE 2008a and b; Bridges et. al. 2010) depending on site-specific conditions. A summary of project experience with physical controls from previous dredging projects is being developed to provide more details on these challenges, and will be presented in the draft FS. The findings of this summary may be used, in conjunction with the evaluations described in this memorandum, to further refine whether physical controls are assumed for alternatives in the detailed evaluation of alternatives.

The ultimate need for operational or physical controls for specific SMAs will be made after further evaluation during remedial design. Some of the challenges associated with physical controls that will need to be considered and further discussed in the draft FS include:

- Challenges associated with moderate- or high-energy areas
- Challenges associated with areas of significant tides or river currents, and significant water depths
- Challenges associated with ongoing river activities where physical controls might interfere with normal daily operations for site users
- Limitations associated with controlling the release of dissolved contaminants.

As noted above, this determination will be made for the FS based on the evaluation approach described in this memorandum, summaries of experiences at other sites, and discussion of the implementation challenges.

WATER QUALITY EVALUATIONS TO DETERMINE NEED FOR PHYSICAL CONTROLS

The potential need for physical turbidity controls for purposes of the FS will be based on evaluations of potential water quality impacts resulting from sediment resuspension and associated contaminant release due to dredging operations. The water quality evaluations will include computer simulations of potential resuspension from dredging (i.e., the U.S. Army Corps of Engineers [USACE] DREDGE model [Hayes and Je 2000]). Future evaluations may also include the evaluation of dredge elutriate test (DRET) data from sediment samples that would be collected as part a subsequent project phase.

DREDGE Modeling Overview

To evaluate the need to include physical controls in FS alternatives, potential water quality impacts from dredging were simulated using the USACE DREDGE model according to the following approach:

- The DREDGE model was used to estimate total suspended solids (TSS) concentrations at 100 meters (m) downstream from the point of dredging. DREDGE couples resuspension source models with a far-field transport model (Gaussian dispersion model and Stokian settling model in a uniform flow field). The 100 m distance was used in accordance with EPA's December 18, 2010 FS comments.
- DREDGE-calculated TSS concentrations were used in combination with calculated average and maximum sediment concentrations of indicator chemicals (ICs) to estimate in water IC concentrations. IC content of the bulk sediment removed was assumed to be identical to the IC content on resuspended material because the entire bulk sediment concentration was applied to the TSS.
- Background water concentrations were added to the computed constituent concentration as described above. The resulting total concentration was compared to state and federal acute water quality criteria (WQC) and other available screening values where acute WQC were unavailable (per EPA's December 18, 2010 comments).

Additional details on the model are provided below.

DREDGE Model Background

DREDGE is a module of the Automated Dredging and Disposal Alternatives Modeling System (ADDAMS) distributed by USACE through the Environmental Laboratory, USACE Research, and Development Center Waterways Experiment Station. DREDGE is a steady-state screening-level model that estimates the rate at which bottom sediments become suspended into the water column as the result of dredging operations and estimates the resulting suspended sediment concentrations. DREDGE consists of a combination of a resuspension source model with a Gaussian plume transport model and Stoke's law of settling in a uniform flow field that describes the dispersion and settling of particles downstream. Resuspension terms can be predicted using the Turbidity Generation Unit (TGU) and Correlation source strength models, or a user-selected estimate of resuspension can be used. These are combined with information about site conditions to simulate the size and extent of the resulting suspended sediment plume under steady-state conditions.

Resuspension Estimates

The rate of resuspension simulated by the DREDGE model was used to estimate potential water column concentrations. A number of factors affect the rate of sediment suspended in the water column. A summary of the factors that affect the amount of sediment suspended in the water column, as well as the assumptions used in the evaluation, are discussed below:

- **The type of dredge equipment used**: A mechanical dredge operation was considered to be representative of the likely scenario for this evaluation [1].
- **The size of the dredge bucket**: This evaluation assumed a 10 cubic yard mechanical open dredge bucket, which is a size readily available to local marine contractors and has been used on similar projects (e.g., Port of Portland Terminal 4 dredging).
- **Sediment resuspension loss:** A range of sediment loss rates, as the percentage of the dredged sediment mass that is resuspended and transported in the water column as a plume, was assumed for mechanical dredging (stepped range of 0.5, 1, 3, and 5 percent loss). Observed resuspension rates (percent loss) from bucket operations range from approximately less than 0.1 to greater than 5 percent and may be higher depending on equipment type and operation (USACE 2008b; Bridges et.al. 2010). Resuspension rates are expected to be 2 to 6 percent for a majority of the dredging; however, the actual rate will be a function of many factors. Higher loss rates are typically associated with factors such as debris removal, natural impediments (e.g., cobbles, rock, other obstructions), and combinations of site and operational conditions such as sediment properties, water depth and currents, actual dredging equipment type, and dredge operator skill.
- **Physical properties of the site and sediment**: Site condition and geotechnical data such as water depth, river current, in-situ dry density, and d_{50} particle size data are key variables in the DREDGE model that affect TSS estimates. Input values used for these variables were developed by averaging available site and geotechnical data within the evaluation area.

Background TSS concentrations were neither evaluated nor included in the DREDGE-calculated TSS concentrations.

TSS Plume Estimates

Sediment resuspension loss rates calculated using the DREDGE model are used to predict the amount of resuspended sediment that could potentially leave the immediate vicinity of the dredging operation. The plume of suspended solids (TSS Plume) generated as a result of dredging depends on a number of factors. The rate at which sediment particles are introduced into the water column in the immediate vicinity of the dredging operation contributes to the near-field source estimate, which is provided in units of both kilogram/second (kg/sec) and percent loss. Source strength is taken as the rate at which sediment leaves the area, which can be computed using this expression for sediment loss:

$$S_{loss} = \frac{100 m_R}{(q_s \times \gamma_{sed})}$$

[1] The FS is not ruling out hydraulic dredging as a potentially viable method for some areas and situations. However, we expect that mechanical dredging will be used much more often in Portland Harbor, and thus, this option provides the most widely applicable results. The draft FS will discuss situations where hydraulic dredging might be a viable technology and what, if any, implications this may have to alternative evaluation results.

Where:

m_R = mass rate of sediment resuspension (kg/s)

q_s = volume rate of sediment removal (m^3/sec)

γ_{sed} = bulk density of sediment (kg/m^3)

S_{loss} = sediment loss rate (%)

The DREDGE model utilizes a 2-D vertically averaged far-field transport model for mechanical bucket dredging that combines simplifying assumptions and characteristics of the dredge operation to allow analytical solutions to the transport equation:

$$TSS_{wc}(x,y) = \frac{m_R}{uh\sqrt{4\pi k_y \frac{x}{u}}} \exp\left[\left(\frac{y^2}{4k_y \frac{x}{u}}\right)\left(\frac{\omega x}{uh}\right)\right]$$

Where:

$TSS_{WC}\ (x,y)$ = TSS concentration at any x,y coordinate (mg/L)

m_R = predicted rate of sediment suspended by the mechanical dredge bucket and available for transport away from the dredging operation (kg/s)

ky = lateral (y-direction) diffusion coefficient normal to the direction of flow (y-direction) (m^2/sec)

u = ambient velocity in x-direction (m/sec)

ω = settling velocity of suspended sediment particles (m/sec)

h = water depth to bottom of dredge prism (m)

DREDGE Model Scenarios Considered

A variety of DREDGE model scenarios were developed to capture the range of potential conditions observed during dredging for various physical and operational characteristics, ICs, and for site-specific conditions within each SMA.

DREDGE simulations were run for each SMA. The following DREDGE input parameters were varied based on site-specific SMA conditions identified from data gathered during previous investigations in the Lower Willamette River:

- Average sediment particle size

- Average sediment specific gravity of solids
- Average sediment density
- Average SMA water depth
- Average SMA current velocity
- Assumed depth of dredging (to estimate source strength, based on mass of material removed and percent loss modeled for a given scenario)

The following factors were the same from SMA to SMA in the DREDGE evaluation:

- Assumed dredge bucket size (10 cy)
- Assumed range of sediment resuspension loss scenarios (0.5 percent, 1.0 percent, 3.0 percent, and 5.0 percent)
- Assumed dredge cycle time

Water Quality Predictions

The DREDGE TSS results were used in the water quality evaluation, which focused on a subset of chemicals based on toxicity, persistence, and mobility properties. This selection process is described more in the March 16, 2011 LWG tools memo *Identification of "COCs" and Contaminant Mobility Evaluation Criteria for the Draft Feasibility Study*. The following is the list of chemicals that were included in the water quality evaluation:

- 4,4'-DDD
- 4,4'-DDE
- 4,4'-DDT
- Arsenic
- Benzene
- Benzo(a)pyrene
- Bis(2-ethylhexyl) phthalate
- Chlorobenzene
- Copper
- Mercury
- Naphthalene
- Total PCBs
- Vinyl chloride

Both the average chemical concentration and the maximum chemical concentration in each SMA were evaluated for potential water quality impacts. Estimated water quality concentrations downstream of the dredge operation were simulated based on the TSS concentrations predicted by the DREDGE model in combination with the dredge sediment concentration for the constituents of interest. TSS concentrations formed the basis for estimating water column constituent concentrations using the fundamental relationship:

$$C_T = (1 \times 10^{-6})\ (M_{constituent} \times TSS) + C_{back}$$

Where:

C_T	= total constituent concentration in water column (mg/l)
$M_{constituent}$	= constituent bulk sediment concentration in situ sediment (mg/kg)
TSS	= total suspended solids 100 m downstream from the dredging operation (in mg/l)
C_{back}	= background water column concentration (mg/l)
(1×10^{-6})	= conversion factor for kg/mg

Table 1 presents a summary of the results of the DREDGE TSS modeling simulations and acute criteria exceedances. Two potential exceedances of acute water quality screening values were predicted: one in SMA 14 for 4,4'-DDD resuspension loss scenarios of 1 percent or higher and one in SMA 9U for benzo(a)pyrene for a resuspension loss of 5 percent. For all other constituents evaluated, the DREDGE simulation described in this memorandum did not predict exceedances of acute water quality screening values. The results in Table 1 show that exceedances of acute water quality screening values are limited to a small portion of the site under the modeled scenarios, and may further indicate that the need to include physical controls in the FS is limited to a subset areas of the site where select IC concentrations are elevated. The results of the DREDGE modeling will ultimately be used in combination with the other considerations previously mentioned (experience with physical controls at other sites and related implementability evaluations) for FS alternative development related to physical controls.

REFERENCES

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Tables

Table 1. DREDGE Modeling Results for TSS and Associated Acute Criteria Exceedances

		Key DREDGE Model Inputs							TSS for .5 % loss		TSS for 1 % loss		TSS for 3 % loss		TSS for 5 % loss		Acute Exceedances	
AOPC Area/SMA	Dredge Bucket Size (cy)	D50 (um)	Average In-situ dry density (kg / m^3)	Average Specific Gravity	Average Velocity (m/s)	Average Depth (m)	Water Depth to Bottom of Dredge Prism	Average DoC - Remedial Areas (cm)	Source strength (kg/s)	TSS at 100 m downstream from point of dredging (mg/L)	Source strength (kg/s)	TSS at 100 m downstream from point of dredging (mg/L)	Source strength (kg/s)	TSS at 100 m downstream from point of dredging (mg/L)	Source strength (kg/s)	TSS at 100 m downstream from point of dredging (mg/L)	Acute Exceedance? (Y/N)	% Loss and chemical that exceeded Acute Criteria
1A	10	196.14	1302	1.83	0.067	8.3	10.6	234.2	0.23	0.41	0.82	0.31	2.47	0.93	4.12	1.56	N	--
1B	10	32.19	1184	1.64	0.079	14.3	16.2	183.0	0.37	0.71	0.75	1.43	2.25	4.30	3.75	7.17	N	--
2	10	78.68	1259	1.70	0.089	9.5	--	No dredging	--	--	--	--	--	--	--	--	N	--
3	10	132.39	1058	1.70	0.043	9.2	11.3	205.8	0.50	0.34	0.67	0.76	2.01	2.30	3.35	3.80	N	--
4	10	77.46	1083	1.54	0.081	10.1	--	No dredging	--	--	--	--	--	--	--	--	N	--
5	10	107.26	1085	1.69	0.066	10.0	11.5	152.1	0.34	0.62	0.69	1.26	2.07	3.77	3.44	6.30	N	--
6	10	376.33	912	1.68	0.035	13.4	14.6	114.2	0.29	0.00	0.58	0.00	1.73	0.001	2.89	0.001	N	--
7	10	161.20	1081	1.54	0.046	5.2	6.7	147.5	0.34	0.24	0.68	0.48	2.05	1.44	3.40	2.40	N	--
8	10	112.71	1296	1.88	0.052	9.4	11.6	216.5	0.41	0.57	0.82	1.14	2.50	3.40	4.10	5.70	N	--
9 Downstream	10	43.19	917	1.56	0.099	13.9	15.4	152.9	0.29	0.52	0.58	1.03	1.74	3.10	2.90	5.20	N	--
9 Upstream	10	90.33	1137	1.74	0.104	12.6	14.9	227.9	0.36	0.50	0.72	1.10	2.20	3.30	3.60	5.55	Y	5% (BaP)
10	10	67.86	1158	1.58	0.072	8.9	10.6	169.5	0.37	0.98	0.73	1.94	2.20	5.84	3.70	9.70	N	--
11	10	57.06	888	1.54	0.086	7.9	9.3	134.7	0.28	0.82	0.56	1.65	1.70	4.90	2.80	8.30	N	--
12	10	35.72	765	1.50	0.090	9.7	10.8	107.4	0.24	0.64	0.48	1.28	1.45	3.87	2.40	6.45	N	--
13	10	29.93	778	1.53	0.053	7.6	9.1	147.6	0.25	1.01	0.49	1.99	1.48	6.00	2.46	10.00	N	--
14	10	108.87	1072	1.69	0.08	10.28	12.04	175.8	0.34	0.60	0.68	1.20	2.00	3.50	3.40	5.94	Y	1%, 3%, 5% (4,4'-DDD)
15	10	16.65	869	1.58	0.013	2.4	5.5	304.8	0.28	3.58	0.55	7.00	1.65	21.10	2.75	35.00	N	--
16	10	18.81	952	1.59	0.048	12.1	13.5	141.4	0.30	0.62	0.89	0.60	1.81	5.40	3.00	8.93	N	--
17 Downstream	10	42.88	1195	1.60	0.055	13.9	15.5	153.9	0.38	0.87	0.76	1.76	2.30	5.24	3.78	8.70	N	--
17 Swan Is.	10	91.58	1053	1.70	0.012	10.3	11.9	158.1	0.33	0.32	0.67	0.64	2.00	1.90	3.30	3.20	N	--
18	10	43.63	933	1.59	0.055	8.3	10.1	174.2	0.30	1.03	0.59	2.00	1.77	6.10	2.95	10.10	N	--
19	10	39.06	1019	1.63	0.049	7.0	9.1	207.8	0.32	1.30	0.65	2.60	1.94	7.75	3.23	12.90	N	--
20	10	84.49	1105	1.79	0.035	6.8	9.0	224.3	0.35	0.79	0.70	1.60	2.10	4.70	3.50	7.87	N	--
21	10	202.33	1242	1.64	0.073	12.3	13.3	100.3	0.39	0.27	0.79	0.54	2.40	1.60	3.90	2.70	N	--
22	10	61.88	1057	1.52	0.057	7.6	9.3	172.5	0.33	1.12	0.67	2.25	2.00	6.75	3.35	11.25	N	--
23	10	39.54	888	1.68	0.043	10.5	12.0	152.6	0.28	0.90	0.56	1.81	1.70	5.50	2.80	9.13	N	--
24	10	49.90	1003	1.65	0.091	14.6	16.4	179.2	0.32	0.55	0.64	1.10	1.90	3.30	3.20	5.40	N	--
25	10	143.83	1166	1.75	0.059	10.7	11.5	84.3	0.37	0.40	0.74	0.79	2.20	2.40	3.70	3.90	N	--
26	10	61.30	1170	1.67	0.071	8.2	--	No dredging	--	--	--	--	--	--	--	--	N	--